

FRAGMENTATION IN STELLAR COLLAPSE.

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A three dimensional, Cartesian code has been developed to model molecular cloud collapse and protostellar formation. The basic Eulerian scheme employs spatially second-order accurate, finite difference methods to advance the fluid variables in time. The hydrodynamic equations governing the collapse include the effects of self-gravity, rotation, and radiative transfer. Supplementary equations include Poisson's equation which relates the gravitational potential to the density distribution and a mean intensity equation derived with the Eddington approximation for radiative transfer. The gas pressures and internal energies are determined from equations of state derived for a molecular cloud composed of hydrogen, helium, and heavier elements¹. Rosseland mean opacity tables determined by Pollack et al.² are used to calculate the opacity values.

Initially the effects of opacity, heating, and radiative transfer were ignored, and an isothermal collapse code was developed. This type of scheme is appropriate for the early stages of molecular cloud collapse when the gas remains essentially transparent, and the dust grains radiate away any thermal energy generated by compression. The advective terms in the hydrodynamic equations are evaluated with the van Leer second-order, upwind difference scheme³, while second-order centered differencing is used to calculate the source terms. A second-order accurate scheme is an improvement over previous first-order methods as it results in considerably less numerical viscosity. Green's functions and Fourier transforms are used to solve Poisson's equations⁴.

After the isothermal collapse code had been rigorously tested, a nonisothermal version was developed by adding the energy equation to the basic set of hydrodynamic equations so that the effects of heating and radiative transfer would be included. The radiative flux term is evaluated with the Eddington approximation, and an alternating directions implicit method is used to solve the supplementary mean intensity equation. The Eddington approximation, which assumes that the ratio of the radiation pressure to the energy density is 1/3, is a significant improvement over the more commonly used diffusion approximation which is strictly correct only at large optical depth. A regridding routine was also developed to improve the grid resolution in the later stages of collapse. The nonisothermal scheme was used to follow the gravitational collapse of molecular cloud cores. These calculations differed from previous computations in that the clouds began the collapse with centrally condensed density

distributions and varying amounts of differential rotation. Observations and studies of ambipolar diffusion indicate that cores are likely to have $1/r$ to $1/r^2$ density distributions^{4,5}. Two initial angular velocity profiles were investigated: (1) solid body rotation corresponding to an upper limit for magnetic braking during core formation and (2) differential rotation profiles appropriate for a minimum amount of magnetic braking. The other initial conditions (mass = 4 solar masses, initial temperature = 10K, initial radius = 1.5×10^{-17} cm) were based on radio observations of dense cores in Taurus-Aurigus⁷. All of the models began with similar thermal, rotational, and gravitational energies. Initially, the clouds had average density and angular velocity values of 5.6×10^{-19} g/cm**3 and $4.0-5.0 \times 10^{-13}$ rad/s respectively.

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